

NRL Report 4491

INTERCEPT THRESHOLDS PANORAMIC, TIME BASE, AND AUDIO INDICATORS

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Countermeasures Branch
Radio Division

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CONTENTS

Abstract	ii
Problem Status	ii
Authorization	ii
INTRODUCTION	1
PROCEDURE	2
Implementation	2
Details of the Experiment	3
Functions of Test Director and Observer	4
Scoring	4
Graphing	4
SUGGESTED PROCEDURE FOR EVALUATING FUTURE INTERCEPT INDICATORS	5
RESULTS	6
S/N Thresholds	6
Response to Short Bursts	7
DISCUSSION OF RESULTS	8
CONCLUSIONS	9
RECOMMENDATIONS	10
ACKNOWLEDGMENTS	10
REFERENCES	10
BIBLIOGRAPHY	11

ABSTRACT

As part of a continuing program in the quest for an intercept indicator of optimum effectiveness, this experiment was designed to determine the average observer's success in detecting threshold signals through the use of various indicators. The panoramic presentation (panscope) threshold characteristics of an AN/APR-9 intercept receiver were determined at the Naval Research Laboratory before and after modification of the i-f and panscope circuitry. In further threshold tests, the NRL multigun analyzer was substituted for the panscope. A comparison was also made of the audio thresholds of both the AN/APR-9 and the NRL multigun analyzer.

The following facts were established:

1. Narrow-band panoramic systems, such as those contained in the AN/APR-9, AN/BLR-1, AN/SLR-2, etc., have relatively good response to cw signals and wide-pulse radar signals, but relatively poor response to narrow-pulse radar signals.
2. The NRL multigun analyzer, which incorporates wide-band circuitry and time-base presentation, is superior to the panscope with regard to narrow-pulse response and response to extremely short bursts.
3. The audio response of the NRL multigun analyzer, which incorporates high-level pulse stretching and other audio refinements, is superior to the audio response of the AN/APR-9.
4. Audio and wide-band video threshold levels are practically identical.

It was concluded that more effective intercept sensitivity than is now available could be obtained by employing a combined indicator with simultaneous panoramic, time base, and audio presentations.

PROBLEM STATUS

This is an interim report; work on the problem is continuing.

AUTHORIZATION

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INTERCEPT THRESHOLDS PANORAMIC, TIME BASE, AND AUDIO INDICATORS

INTRODUCTION

The initial purpose of this experiment was to determine the signal-to-noise (S/N) threshold of a standard AN/APR-9 intercept receiver with respect to the pulse width (pw) and pulse-repetition frequency (prf) of a pulse-type signal. This pulse intercept threshold study is a continuation and extension of the cw intercept problem investigated by Beck and others (1), (2). The S/N threshold is defined as the second detector S/N power ratio in db which enables test signals to be found by an average observer with 50-percent success.

A modified AN/APR-9 and the newly developed NRL multigun analyzer were next evaluated, and consideration was given to the feasibility of integrating these equipments into a combined indicator-analyzer. Modifications to the AN/APR-9 consisted of improving the panscope and narrow-band video circuitry and extending the wide-band video response (3). The NRL multigun analyzer is a 5-trace slave-sweep linear time-base indicator designed to receive signals from the wide-band video output of an intercept receiver. Although fundamentally similar in principle to the AN/SLA-2 pulse analyzer, it contains redesigned and improved circuitry (4). One important electronic addition not incorporated in the AN/SLA-1 and AN/SLA-2 is an improved audio system. Pulse stretching is accomplished at a high audio level; frequency response is improved through the elimination of audio transformers. The audio output of the NRL multigun analyzer is terminated in a headphone jack.

A supplementary investigation was made concerning the effects produced on both indicators and observers by bursts of a limited number of pulses. Results of this study were in agreement with a similar investigation by Haller, Raymond, and Brown, Inc.

A frequency-scrambled diminishing-amplitude series of continuous, simulated radar signals was fed to an AN/APR-9 in a dark, quiet test area. Test director, observer, intercept receiver, and associated test equipment were housed in a shielded room. The director's duties were to explain the procedure to each observer, feed a sequence of signals to the AN/APR-9, and record the successes and failures of the observer. It was the observer's task to tune the receiver as prescribed, concentrate on the indicator before him, and attempt to find each signal. Various investigators have previously conducted so-called signal-position experiments in which the observer was required to state, by reason of either observation or guess, the location of a continuous signal in the presence of noise, where the signal was located at one of several possible frequency positions on the panoramic display of a nonscanning receiver. In those previous experiments the instant of signal presentation and the standardized length of presentation time were made known to the observers, who were instructed in case of doubt to guess at which of the marked signal positions the signal existed. In contrast, the experiment described herein is set up in such a manner that spatial and temporal references are unavailable to the observer. After a variable time interval during which the observer's attention must be constantly focused on the scanning display, the signal travels across the panscope and remains in view only for about half a second. The observer clearly succeeds or fails to center each signal; guessing does not influence the results appreciably. This experiment reflected the decreased probability of intercepting low prf radar signals on a panscope such as that of the AN/APR-9, which has a 13-cps horizontal sweep frequency. The results are presented as a series of 3-dimensional curves that show the S/N level required for 50-percent success.

In NRL Memorandum Report 200 the AN/APR-9 modifications are described, whereas the present report is a threshold study which deals largely with the effect of certain of those modifications. Conclusions apply in general to the AN/SLR-2 and AN/BLR-1 ship-board and submarine adaptations of the AN/APR-9, and to the AN/APA-74, AN/SLA-1, and AN/SLA-2 multigun pulse analyzers. The method of evaluation can be duplicated for application to future intercept equipment. The 3-dimensional technique is applicable, in general, to problems that involve simultaneous families of curves.

PROCEDURE

Implementation

A simulated countermeasures intercept observation compartment housed the indicators, remote control, and observer, and the experiment was controlled by a director from outside this darkened booth. A block diagram of the setup is shown in Fig. 1.

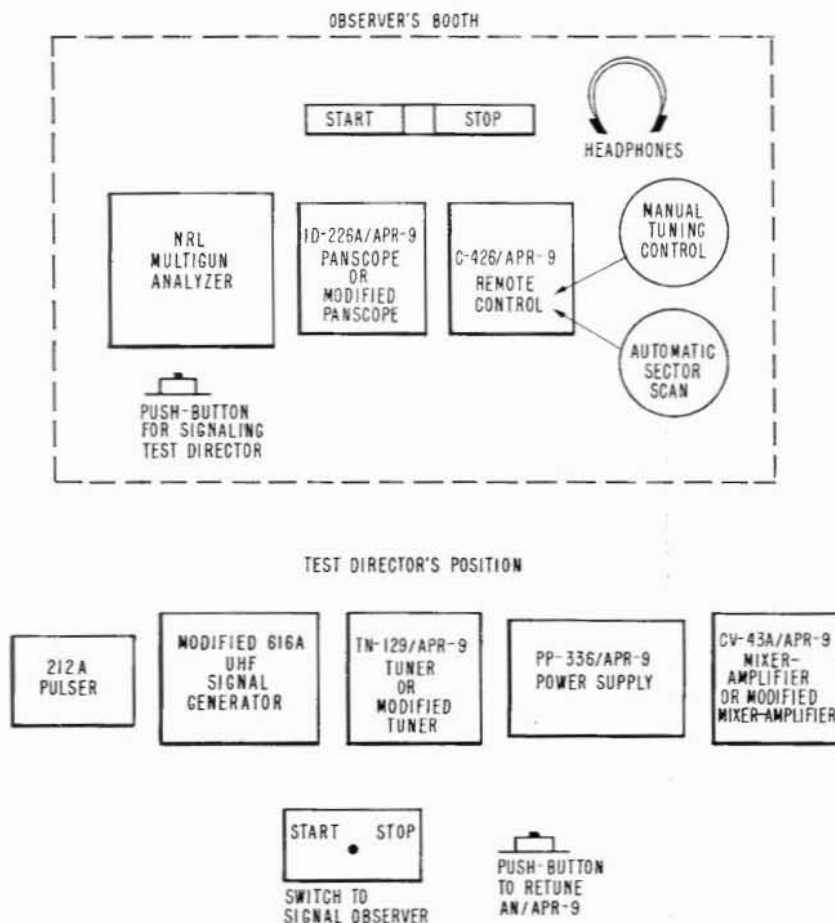


Fig. 1 - Block diagram of test equipment setup

A Hewlett Packard model 616A uhf signal generator was modified for 0.2- μ sec pulse output as follows. A variable-voltage network (using a dry battery insulated from the chassis) was inserted in series with the reflector lead of the reflex klystron oscillator. A panel jack was installed to feed modulating waveforms to the collector through a high-voltage blocking capacitor. Modulation procedure consisted of increasing the collector bias until the klystron just ceased to oscillate. The output from a Hewlett Packard model 212A pulser was then fed to the 616A klystron through the panel jack; the amplitude of the modulating pulse was sufficient to force the klystron into oscillation in accordance with this pulse waveform.

A latching and automatically de-energizing relay network was added to the automatic sector-scan circuit of the AN/APR-9 so that when the director pressed a switch button the receiver would retune and stop automatically on the frequency determined by the setting of the low-limit knob on Remote Control C-426/APR-9. Standard and modified S-band heads, TN-129/APR-9 (2.3 to 4.45 kMc), were used throughout the experiment.

An audio signal controlled by a thumb switch in the booth was the observer's means of indicating that he had centered what he considered to be a signal and was ready for another trial. Illuminated START and STOP signs in the booth were controlled by the director as a means of regulating the scanning procedure. In order that the observer would have no indication of the tuner frequency, the counter at the panscope was disconnected. For an audio indicator, the observer used a pair of dynamic 600-ohm headphones. Mounted in front of the NRL multigun crt display were two filters: a dark green filter for increased signal contrast and a deep yellow one for blue flash absorption.

Maximum sensitivity occurred when the NRL multigun analyzer gain was advanced until the traces just barely triggered continuously on noise; the AN/APR-9 gain was adjusted so that about a quarter of an inch of grass appeared on the panscope. Only one indicator at a time was made operative.

Details of the Experiment

The director fed consecutive test signals to the receiver in subgroups of five. Each subgroup consisted of a random order of the following signal frequencies: 3.1, 3.2, 3.3, 3.4, and 3.5 kMc. Preliminary to each daily run, the equivalent noise voltage was measured at each of the five signal positions, and a record was made of signal-generator corrections for equal corresponding S/N ratios. A normal test run consisted of five to eight 20-signal groups, each group lower in amplitude than the previous one. The number of trials at each amplitude was revised to fifteen and later to ten, with no apparent degradation of results. The initial twenty signals in each test run were strong enough to be detected almost without fail. The amplitude of each subsequent group was lowered in steps of 1/2 or 1 db until signals became exceedingly difficult to find. Test signals within each group were constant in pw and prf, and the amplitude level was the only variable. Varying the amplitude in the opposite direction — starting with S/N levels that yielded nearly zero success — was found to produce erratic data. About an hour was sufficient for an observer to run through a test group, from nearly 100-percent success down to nearly zero success. To minimize fatigue, each observer was normally limited to one test group in a day.

It is characteristic of the AN/APR-9 sector-scan circuitry that the receiver tunes upward in frequency when the automatic sector switch is thrown on. This results in apparent horizontal movement of signals across the panscope from right to left. On the other hand, this horizontal, visual displacement does not occur on the time-base indicator of the

NRL multigun analyzer; as the receiver scans, signals on this display appear to rise and fall vertically in and out of the noise.

Functions of Test Director and Observer

The director adjusted the pw, prf, and amplitude of the test signal and tuned the AN/APR-9 to a starting frequency somewhere near 3.0 kMc. He then flashed the START sign, which signaled the observer to throw the automatic sector-scan switch to the ON position and to watch for a signal.

If the observer thought he saw a signal, he was supposed to turn the automatic sector-scan switch off and center the signal on the indicator by means of the manual tuning control. He was not permitted to tune manually more than about thirty megacycles because the manual tuning control was intended to be used in this experiment merely for centering signals and not for scanning. If he decided after tuning manually to no avail that he had actually not seen the signal, he was supposed to turn the automatic scan switch back on and resume scanning until he again thought he saw a signal or until he saw the STOP sign, which indicated that he should stop scanning because he had missed the signal. The director then retuned the AN/APR-9 to a starting frequency below the range of signal frequencies and readjusted the signal generator for the next trial.

Scoring

The tuning head, which had a standard built-in frequency indicator, was located at the director's position. If the observer centered the signal, the frequency indicator made this fact clear by registering the exact signal-generator frequency and the director recorded that trial as a success. Conversely, if the observer failed to center the signal, the director recorded the trial as a failure. A series of percentage success scores was obtained — one score for each observer on a particular combination of intercept equipment.

Observers rarely centered false signals. The average observer apparently did not care to guess, nor was he encouraged to do so; his instructions were to be reasonably sure of the presence of signals. The guessing factor was eliminated, since in tactical counter-measures operations the threshold is well above the guessing level.

Graphing

The scores of various observers who had participated in identical tests were plotted against S/N ratio on a single graph, and these scores formed a cluster of points at each S/N ratio used in the tests. A smooth curve that resembled the "betting" curves of Ashby, Josephson, and Sydoriak (5) was drawn through the approximate centers of the clusters. This "threshold" curve showed the effect of the S/N ratio upon the percentage success of an "average" observer. A separate threshold curve was plotted for each of several combinations of pw, prf, and equipment. The central portions of all the threshold curves were straight, experimentally reproducible, and related in slope. The 50-percent success point on each curve, at the approximate center of this straight line region, was designated as the S/N threshold.

Data on the audio indicators and the NRL multigun analyzer were obtained in three steps: (a) a few S/N threshold points were established as in the panscope experiment,

(b) numerous points were established by static observation, in which the lowest positively detectable S/N level was noted by the director when the receiver was tuned to a fixed frequency instead of scanning, and (c) the static scale was adjusted to coincide with the S/N thresholds established in the first step. Comparison of data showed that strong correlation existed between this and the afore-mentioned longer method.

Plotting the S/N thresholds in three dimensions against the parameters log pw and log prf yielded a unique 3-dimensionally curved surface for each combination of equipment. All three axes were scaled in logarithmic units; the S/N threshold scale (in db) was inverted so that sensitivity increased in an upward direction.

Each graph was constructed of twenty-one 3/32-inch balsa sheets spaced 3/16 inch apart, in order to permit the interleaving of any one of several other graphs. The curved top edge of each sheet defined the S/N threshold for a particular indicator at a constant prf as a function of pw (0.2 to 10 μ sec). A multiplicity of sheets represented prf's ranging from 50 to 5000 pulses per second. The sheets of each graph were held together solidly with two threaded brass rods, and a removable metal base cover served to support a metal coordinate scale in correct reference to the graphs.

SUGGESTED PROCEDURE FOR EVALUATING FUTURE INTERCEPT INDICATORS

Since the S/N thresholds of future intercept equipment will be in some measure dependent on the same parameters which were involved in this experiment, various means were evolved for speeding up the collection of data in the scanning-type experiments. One test frequency instead of five would probably be sufficient to establish the S/N threshold if the frequency interval between the start of each scan and the signal were varied in a limited random fashion. Such a variation would insure the observer's constant attention and his inability to predict the instant of signal presentation. A few advantages of such a scheme are listed as follows:

1. The noise level at only a single frequency need be established.
2. The signal generator would be set once and thereafter left untouched, except for changing the attenuator setting after each group of trial runs at a given S/N level.
3. The cluster of points would be more compact.
4. Ten trials at each S/N level would be ample.
5. This method would be faster and much less fatiguing for both observer and director.
6. Accuracy would be well within expeditious limits; relative accuracy would be improved.

A clutch-crank mechanism could be adapted to the existing screwdriver frequency adjustment on the front panel of the tuner, and by this means, the director could reset the tuner to a somewhat different frequency as a starting point for each new trial.

RESULTS

S/N Thresholds

In Plate I the S/N thresholds of five indicators are shown graphically, along with graphic intersections between pairs of these S/N thresholds. Standard and modified AN/APR-9 panscope S/N thresholds are compared in Plate Ia and Ib (at top of page). The AN/APR-9 headphones, the NRL multigun analyzer headphones, and the NRL multigun analyzer crt display S/N thresholds are shown in Plate Ic, If, and Ii (left-hand side of page). In the remaining six spaces, intersections of these five graphs are arranged in "mileage chart" form (Plate Id, Ie, Ig, Ih, Ij, and Ik).

Each leaf of all graphs shown in Plate I is a plot of S/N threshold in db versus $\log(pw \times 10^6)$. As contrasted to a linear plot, this logarithmic relationship results in an expanded scale in the narrow-pulse region and large angles of intersection between the various surfaces.

Effective sensitivity increases with height in these graphs. The intersection between any pair of surfaces is a line that contains equally favorable S/N thresholds. On either side of this line, the visible surface represents the more sensitive indicator with reference to the respective coordinate values of pw and prf. In any area, portions of surfaces representing the less sensitive indicator are concealed. Thus, each pair of intersecting graphs shows in which domain each of two indicators can be expected to be of greatest help to an average observer in the detection of threshold signals.

The following paragraphs serve to explain each graph and the various interrelationships in Plate I.

Plate Ia — Panscope, Standard AN/APR-9 — Response to pulse widths below 2 μsec deteriorates rapidly.

Plate Ib — Panscope, Modified AN/APR-9 — Response to pulse widths below 1 μsec deteriorates rapidly, but is nevertheless superior to the panscope response of the standard AN/APR-9. The improved narrow-pulse response is a result of the modified video circuitry following the 42-Mc detector. No changes were made in the preceding 42-Mc i-f stage. Deterioration of response with low prf is essentially the same in these two indicators, since this characteristic is a function of panscope sweep frequency rather than of bandwidth. Sweep frequency is the same in both indicators.

Plate Ic — Headphones (AN/APR-9) — On this logarithmic plot, the response deteriorates rapidly but almost linearly with narrow pw and low prf. Sensitivity at high prf depends on the high-frequency response of the human ear, which varies widely from person to person.

Although the data for this graph pertains directly to the modified AN/APR-9, the standard AN/APR-9 audio characteristics are practically identical, except in the very-narrow-pulse region. For the purpose of simplification it is therefore assumed that this curve represents the audio characteristics of either the standard or the modified AN/APR-9.

Plate Id — (c) vs. (a) — By interleaving Plate Ia and Ic, it is seen that in the standard AN/APR-9 the audio threshold is more favorable than the panscope threshold with signal pulse widths less than about 1 μsec (provided the burst length is not too short*).

*For a discussion of burst length effect, see page 7.

Plate Ie — (c) vs. (b) — Interleaving Plate Ib and Ic shows that in the modified AN/APR-9, headphone output is more sensitive than the panscope circuit for pulse widths below about $0.2 \mu\text{sec}$ (provided the burst length is not too short).

Plate If — Headphones, NRL Multigun Analyzer — Response deteriorates rather linearly with decreasing log pw and log prf. The S/N threshold is shown by this graph to be more favorable than that of the AN/APR-9 headphones (blue) for signals of narrow pw and/or low prf.

The modified AN/APR-9 was used in acquiring these data. It is assumed, however, that if a standard AN/APR-9 had been used results would be practically identical except in the very-narrow-pulse region. Analyzer audio characteristics at $1 \mu\text{sec}$ with either receiver would be about the same as these.

Plate Ig — (f) vs. (a) — The combination of Plate Ia and If shows that the audio response of the NRL multigun analyzer is more sensitive than the panscope in the standard AN/APR-9 to signals below about $1.5 \mu\text{sec}$ in pulse width (provided the burst length is not too short).

Plate Ih — (f) vs. (b) — When Plate Ib is interleaved with Plate If it becomes evident that the audio response of the NRL multigun analyzer is more sensitive than the panscope in the modified AN/APR-9 to signals below about $0.25 \mu\text{sec}$ in pulse width (provided the burst length is not too short).

Plate Ii — CRT Display, NRL Multigun Analyzer — Deterioration in response is gradual and nearly linear with respect to both log pw and log prf. In the threshold shown here the presence of a signal can be established, but the signal level is not quite high enough for the prf to be determined. The signal is barely apparent, during the tuning process, as a slight change in the appearance of the left edge of one or more of the traces.

For the purpose of simplification, this curve is assumed to represent the NRL multigun analyzer response in conjunction with either the standard or modified AN/APR-9. Although this graph directly pertains only to the equipment combination which includes the modified AN/APR-9, the standard AN/APR-9 wide-band video characteristics are practically identical, except in the very-narrow-pulse region. Analyzer characteristics in the $1\text{-}\mu\text{sec}$ region with either model of the AN/APR-9 would probably be identical.

Plate Ij — (i) vs. (a) — The combination of Plate Ia and Ii reveals that in the standard AN/APR-9 panscope, response to pulses of shorter duration than $1.5 \mu\text{sec}$ is inferior to the response of the NRL multigun analyzer display.

Plate Ii — (i) vs. (b) — The graphs in Plate Ib and Ii intersect in a line which shows that the NRL multigun analyzer display is more sensitive to signals with pulse widths below about $0.3 \mu\text{sec}$ than the panscope in the modified AN/APR-9.

Response to Short Bursts

An audio burst consisting of only a few pulses is heard as a click that lacks a distinguishable pitch. By means of a Potter predetermined electronic counter (model 141D) and associated test equipment, it was observed that the audio effect of the number of pulses in a burst varies with prf (Fig. 2). A burst of six or fewer pulses at a prf of 2000, which corresponds to a maximum primary radar installation range of 40 nautical miles, is indistinguishable from a noise spike in the audio output of an intercept receiver. Such a burst at a prf of 4000 (range — 20 miles) can contain up to ten pulses.

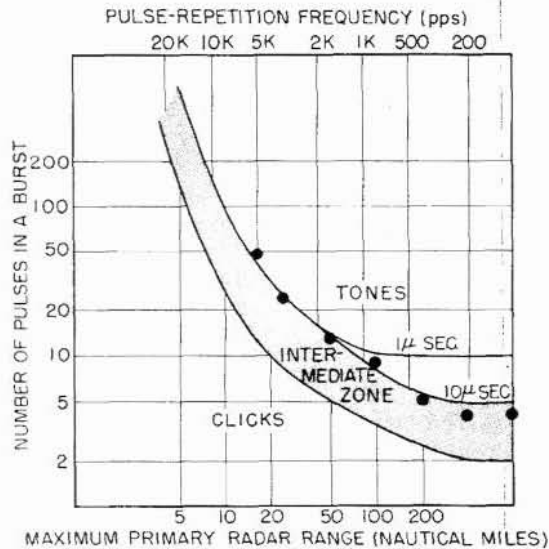


Fig. 2 - Effect of number of pulses in a burst vs. prf and maximum primary radar range

The curve bounding the "CLICKS" zone was obtained with a pw of 27 μ sec, which was the widest pulse obtainable from the particular signal generator used in the tests. It was shown by the curve bounding the "TONES" zone that for a burst to sound like a tone more pulses are needed as the pw is decreased. Recent verification of this work is represented in Fig. 2 by the series of points, which were taken from the 10- μ sec "tonality" curve by Haller, Raymond, and Brown, Inc.

The maximum primary radar range determines the lowest radar transmitter prf which can be employed if, for example, ambiguity is to be avoided on a type "A" presentation. Range is included in Fig. 2 to show in practical terms the area in which such intercept equipment as a crystal-video receiver, for example, is of little use. In contrast to the limited response of such aural systems, the NRL multigun analyzer video time-base display discriminates against short bursts only inasmuch as the observer finds a signal more difficult to "read" because of the instantaneous nature of the flash and the corresponding lack of phosphorescent intensity buildup.

DISCUSSION OF RESULTS

In this study, graphic trends are considered to be more important than the absolute values of individual points. Rather than emphasize the superiority of any particular indicator, the direction of future development is stressed, for it is realized that any equipment will in time become obsolete. Although the S/N thresholds developed in this laboratory experiment might not be realized in tactical operation, the trends with respect to the parameters pw, prf, and burst length are valid indications of what to expect.

Panscope response is inherently poor for narrow-pulse signals primarily because the panscope is fed from a 42-Mc i-f stage which has a bandwidth of only 0.6 Mc. The available

video bandwidth is thus about 0.3 Mc, which limits the pulse response to about 3 μ sec. On the other hand, the audio and pulse analyzer networks are fed from a 160-Mc i-f system which has a bandwidth of 20 Mc. In this case, available video bandwidth is 10 Mc, a frequency which corresponds to a minimum pulse width of about 0.1 μ sec.

Panscope response suffers when signal prf's are so low that they approach the 13-cps sweep frequency of the panscope. Such signals resemble noise spikes because only a few pulses occur during the 4-millisecond interval in which the baseline sweeps through the region that corresponds to the frequency response curve of the narrow-band i-f amplifier. A pulse analyzer is also at a disadvantage since a signal, depending on how low the prf is, may possibly appear repetitively only on the last trace or possibly not at all. However, if an intercept signal is strong enough to be detected on the analyzer, a single pulse will appear at the beginning (left edge) of each trace regardless of the prf.

The panscope video circuitry of the standard AN/APR-9 is inadequate; video response is much narrower than that available from the preceding i-f stage which is 0.6 Mc wide. The substantial improvement in narrow-pulse response of the modified AN/APR-9 panscope was obtained merely by widening the video passband in order to take advantage of the i-f bandwidth. Further improvement in this respect is not available because it is intended that the passband of the 42-Mc i-f stage be used to limit the over-all response. This passband cannot be widened without some sacrifice in panscope resolution.

The difference between the audio curves (Plate Ic and If) is most pronounced with signals of low prf and narrow pw. The improvement shown by the NRL multigun analyzer audio is due presumably to high-level stretching and elimination of audio transformers. The audio (headphone) threshold characteristics of both the AN/APR-9 and the NRL multigun analyzer are similar to the video threshold characteristics of the latter indicator. The input to these indicators is taken directly from the wide-band video output of the AN/APR-9.

Both staff engineers and Navy enlisted men were employed as observers in these tests; these two groups yielded essentially identical data. Apparently, any available personnel may be employed as observers.

The following estimated experimental errors of measurement are reflected in the accuracy of the 3-D curves:

Noise level	$\pm 1/2$ db
Signal threshold level	$\pm 1/2$ db
S/N threshold level	± 1 db.

CONCLUSIONS

The panscope is inherently a narrow-band device that has inadequate narrow-pulse response. Although substantial improvements can be made by modifying the receiver, the panoramic type of indicator alone is not sufficient to monitor effectively all types of signals. The AN/APR-9 headphones and the audio and video presentation of the NRL multigun analyzer are both more sensitive than the AN/APR-9 panscope to narrow pulses; for wide pulses, however, the opposite is true. For bursts of a few pulses, the NRL multigun analyzer crt display is far superior. The audio system of the NRL multigun analyzer is superior to that of the AN/APR-9.

RECOMMENDATIONS

Design and construction of countermeasures intercept receivers of the type represented by the AN/APR-9, AN/SLR-2, and AN/BLR-1 series should be modified in order to take advantage of increased sensitivity shown to be obtainable in NRL Memorandum Report 200. Furthermore, the panscope system alone is inadequate, and it should be replaced with an intercept indicator that provides simultaneous panoramic, time base, and audio presentations.

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* * *

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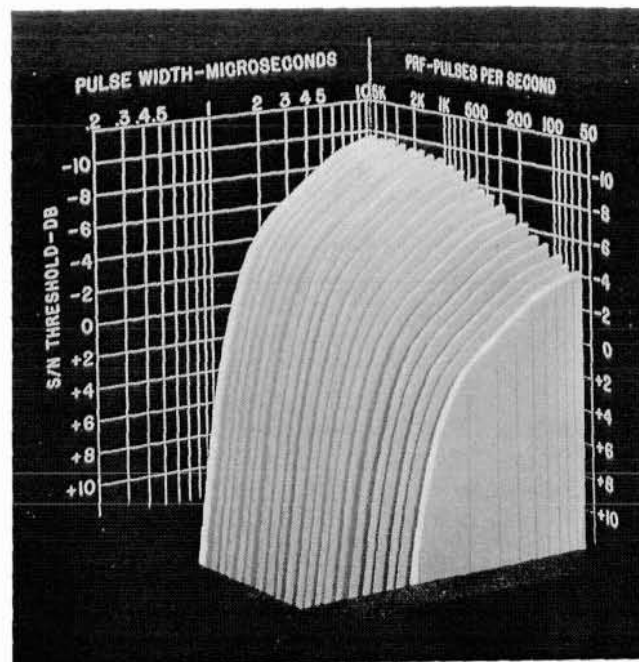
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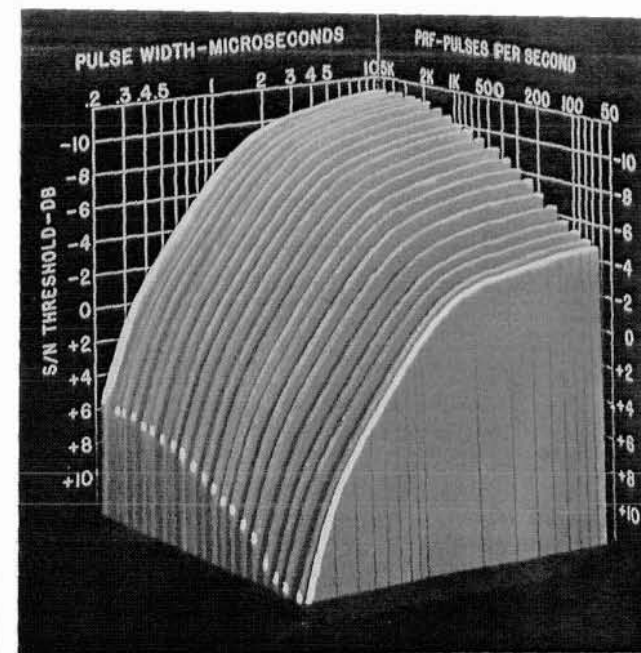
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* * *

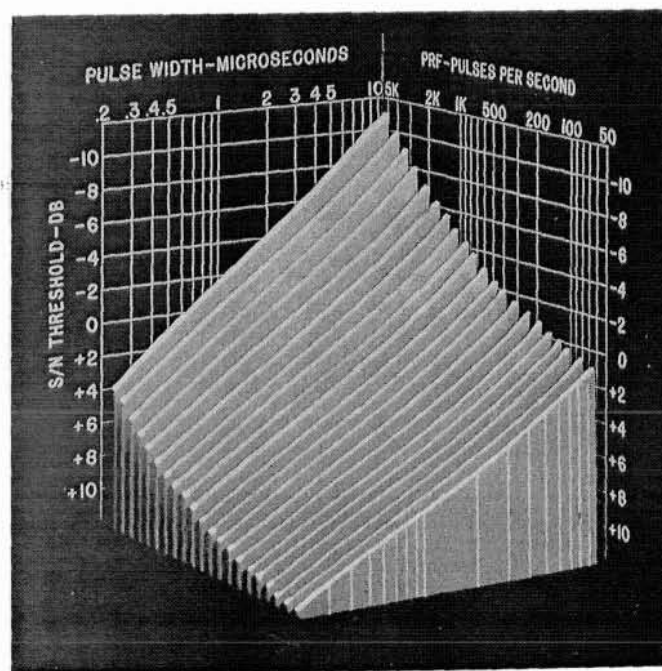
Plate I - INTERCEPT THRESHOLDS



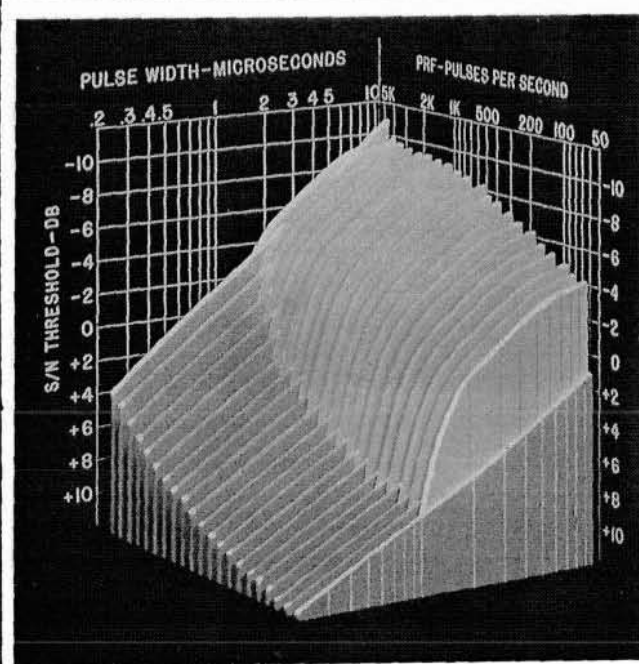
a. Panscope, Standard AN/APR-9



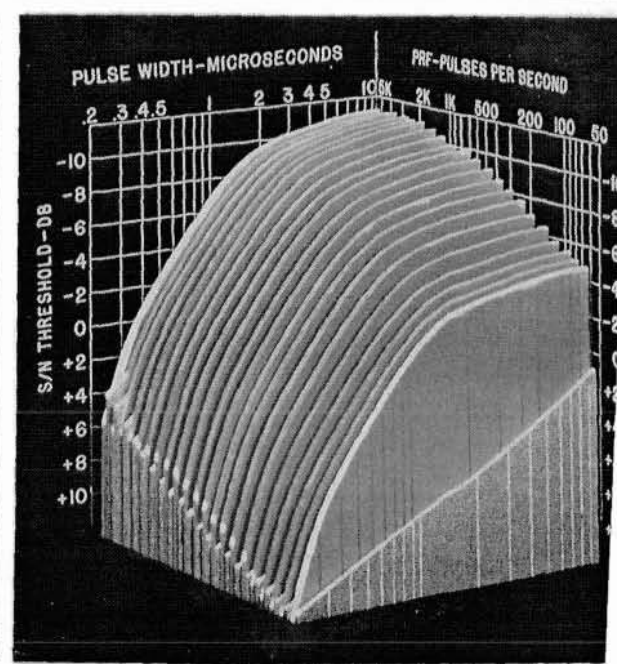
b. Panscope, Modified AN/APR-9



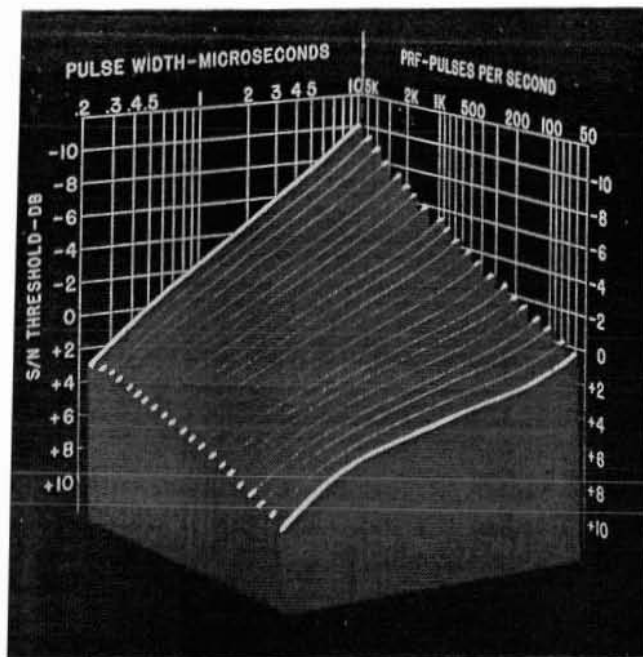
c. Headphones, AN/APR-9



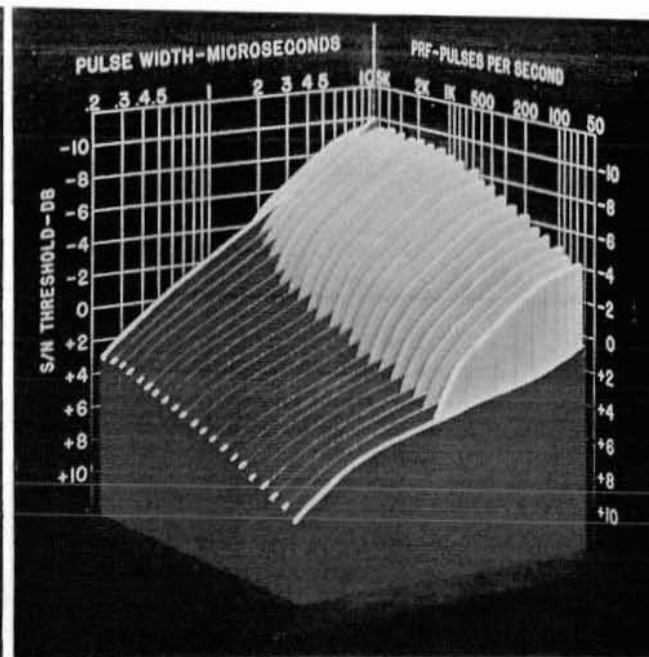
d. (c) vs. (a)



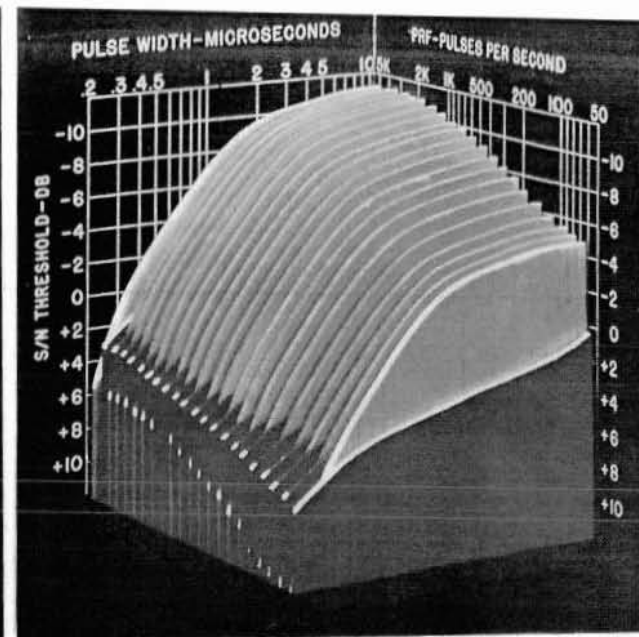
e. (c) vs. (b)



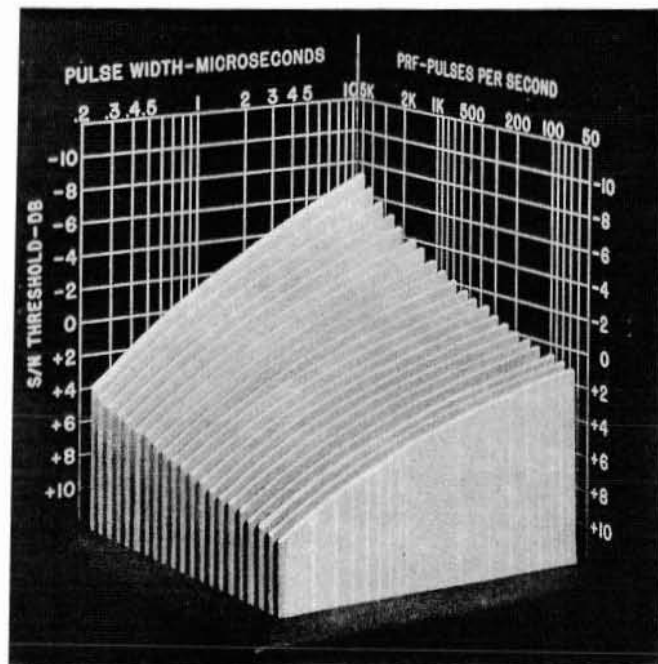
f. Headphones, NRL Multigun Analyzer



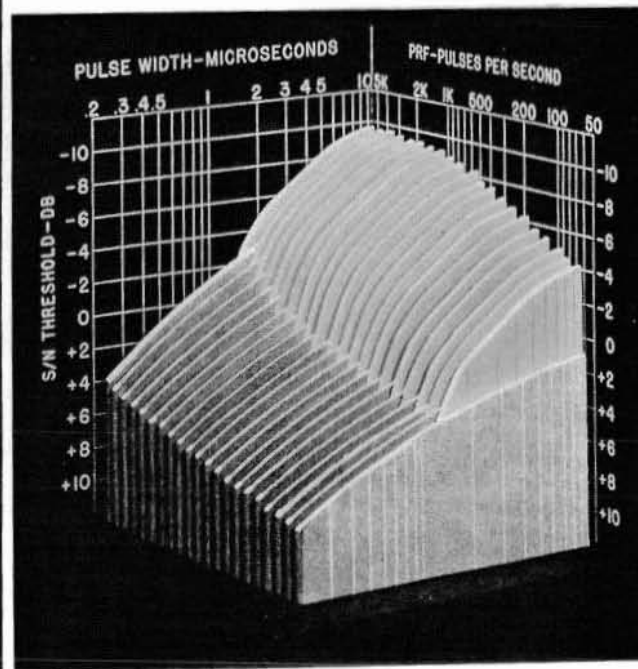
g. (f) vs. (a)



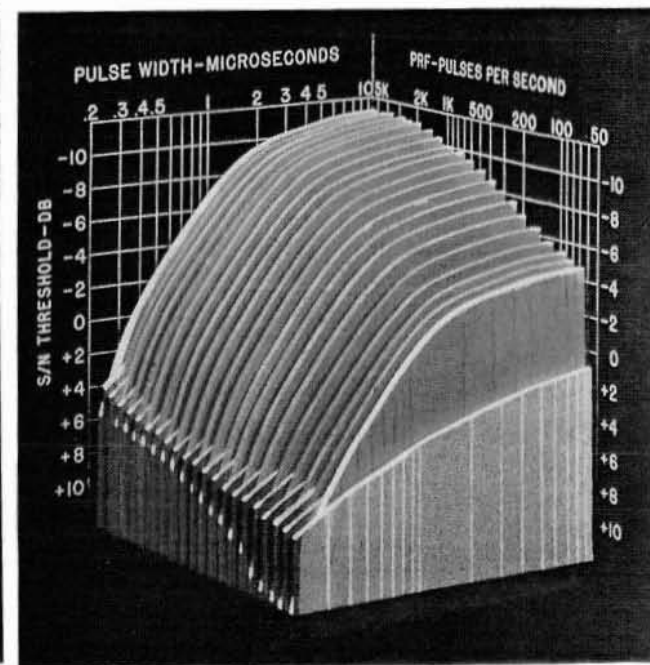
h. (f) vs. (b)



i. CRT Display, NRL Multigun Analyzer



j. (i) vs. (a)



k. (i) vs. (b)